ENGINEERING CASE LIBRARY

ECL 164A

CONCRETE LIQUID OXYGEN RESERVOIR (A)

In 1954 the Linde Company, a Division of Union Carbide Corporation, placed in service a 660,000 gallon reservoir for liquid oxygen. Its oxygen gas capacity was 75,000,000 C.F. (N.T.P.).* This was the successful culmination of over four years of pioneering effort which involved the interaction and cooperation of many persons in various departments of several companies. The reservoir continues in service as of 1970. The knowledge gained from this work demonstrated the suitability of concrete for use as a container for liquefied gases and as a structural material at a temperature of -297°F, the temperature of liquid oxygen.

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*Cubic feet at normal temperature and pressure, -70°F and 760 mm Hg absolute pressure.

Prepared for the Engineering Case Program by Mr. H. C. Kornemann with support from the National Science Foundation.

CONCRETE LIQUID OXYGEN RESERVOIR (A)

This work was initiated because business conditions required larger capacity reservoirs which would have a lower unit cost than obtainable from designs available in 1950. Another incentive for developing the concrete reservoir was that tonnage quantities of strategic materials such as copper, everdur, stainless steel, and steel would not be required.

This was a "captive" project of the Linde Company from its conception through the development, design, construction and operational stages. Linde made use of the available experience of the Preload Corporation and contracted with them to build the concrete reservoir.

In addition to the Preload Corporation, three departments of Linde were involved; namely, (1) Tonawanda Engineering Laboratory (see Exhibit A-1), (2) Construction and Design Department, and (3) Production Department. Geographically, the project involved personnel in New York City, Tonawanda, New York, Chicago, East Chicago, Indiana, and Pittsburgh.

Everybody involved in the project was very much aware of the reservoir's safety requirements and of their own safety responsibilities. The quantities of liquid oxygen being stored were so large that it was necessary to assure and even guarantee that the reservoir could be operated safely and that there would be no disaster which might be caused by liquid oxygen escaping from a damaged or ruptured reservoir. Linde and the Preload Corporation were very much aware of the disaster in Cleveland, Ohio, which resulted from the failure of a large storage tank for liquefied natural gas during the 1930's. That disaster had set back the LNG industry by over 25 years.

BEGINNING OF PROGRAM

During the summer of 1950, Mr. Pete Riede and Mr. John Beckman made an engineering study to determine the economics and feasibility of building liquid oxygen reservoirs of 2,200,000 gallon capacity, ten times larger than the reservoirs installed at that time. The study included many possible design configurations but had one common characteristic—all the inner containers were made of a metal suitable for liquid oxygen temperatures. In August 1950, Mr. George Boshkoff and Mr. Pete Riede from the Linde Engineering Laboratory at Tonawanda, New York, had preliminary discussions with Linde New York Management* in the 42nd Street Union Carbide Building on the engineering study. It appeared that the estimated costs of the very large metal reservoirs would not be as low as desired.

After the office discussions were concluded, the meeting adjourned to a nearby bar. The idea of using concrete as a reservoir material for liquid oxygen was initiated at that time. Several possible designs were sketched on cocktail napkins.

Mr. Pete Riede, Mr. John Beckman, Mr. Ed Kent and Mr. Charles Fails spent the next few months in obtaining available information on the properties of concrete and considering tanks of various configurations. They quickly learned that no information on the physical properties of concrete at -297°F was available. A 5-foot diameter x 4-foot high concrete pipe section was

*S. B. Kirk, President
L. A. Bliss, Vice President
P. B. Pew, Vice President

grouted on to a concrete slab. It was then filled with and held liquid nitrogen (-320°F) without disastrous results. This simple "quick and dirty" test provided the necessary encouragement to continue the concrete reservoir program.

The initial configurations of concrete reservoirs were based on the liquid container being made of either a single or multiple *reinforced* concrete vertical cylinders of large diameter installed in an outer reinforced concrete shell. The space between the liquid containers and outer shell was to be filled with powder insulation. It soon became apparent that reinforced concrete was not the answer. Estimated costs were not competitive with metal tanks. The estimated amount of reinforcing steel required was almost equal to that of an all metal tank. There was also grave concern as to whether the concrete or reinforcing steel might crack or rupture due to temperature strains.

The above problems led to the idea of using *prestressed* concrete for the reservoir. Concrete is prestressed by imbedded wires which are maintained in tension. This takes advantage of the relatively high compressive strength of concrete by imposing compressive loads on those parts of the concrete which would normally be subjected to tensile loads. Prestressed concrete is, therefore, not stressed in (net) tension whereas ordinary reinforced concrete is.

In the fall of 1950, the Linde Tonawanda Engineering Laboratory contacted the Preload Corporation, who were leaders in the design and construction of structures and reservoirs made of prestressed concrete. During the previous 17 years it had designed and built more than 550 prestressed concrete tanks and reservoirs for water, sanitary installations, petroleum products and chemicals.

The Preload Company is a company that engineers and constructs. In fact, 100% of the work that it builds is built to its own design. Preload also operates with a number of selected licensees in foreign countries. During the 1951-1954 period, the annual sales in the United States by the Preload Company, in terms of its own construction activities, was about $2-2.5 million. The tanks were generally used for water or for waste treatment. Although tanks have been used for the storage of petroleum products and for other process applications on a limited scale, the main market is for water storage and waste treatment and water treatment. During the 1951-1954 period, the average size of prestressed concrete tanks was probably in the range of 1.0 to 1.5 MG. Tanks of 10.0 MG had been constructed prior to that time. Over the years the average has increased to where the average sized tank is in the range of about 2.5 MG. The reason for this is the broader acceptance of prestressed concrete and its use on larger tanks.

The Preload Corporation's experience was with reservoirs operating at atmospheric temperature. It had no experience with operating temperatures of -297°F. Discussions between Preload and Mr. Pete Riede of Linde indicated that it might be possible to build a large prestressed concrete reservoir which would be safe to operate and have economic advantages. The Preload Corporation, especially their Chief Engineer Mr. Fornerod, was intrigued with the -297°F temperature application. It would be an engineering challenge and would make available to Preload a large new marketing opportunity.

Messrs. Riede, Beckman, Kent, Fails and others in the Linde Engineering Laboratory therefore implemented a one-year program to determine seven essential physical properties of five types of concrete made

from thirteen mixes. The effects of moisture, thermal cycling and aging were also determined. Most of the tests were conducted with liquid nitrogen at a temperature of -320°F rather than with liquid oxygen because of its greater safety and because the concrete reservoir design might also be used for liquid nitrogen. In most cases the physical properties were improved at -320°F provided that the concrete was dry when cooled to that temperature. For example, even the small amount of frost and moisture which condensed on concrete when warmed in the air from -320°F would cause surface cracks and spalling of the concrete when it was cooled again to -320°F during the thermal cycling tests. The essential physical properties of the concrete finally used are listed in Exhibit A-2.

Messrs. Beckman, Kent and Fails of Linde also investigated the type of prestressing wire to be used at liquid nitrogen temperatures. Normally stainless steel is used for such temperatures, as carbon steel becomes embrittled. They were very pleased to discover that the cold drawn carbon steel wire used by Preload at atmospheric temperature would also be suitable for use at -320°F. The Preload wire had comparable fair elongation and impact values at both room and liquid nitrogen temperatures. The Preload wire had much higher tensile strength, lower impact values and was more notch sensitive than stainless steel wire. The coefficient of expansion of the Preload wire was almost identical with that of concrete whereas stainless steel was about 40% greater. This was important because of the large temperature changes involved. See Exhibit A-3 for physical properties of prestressing wire.

LINDE TONAWANDA ENGINEERING LABORATORY

In 1951 the Linde Tonawanda Engineering Laboratory had about 160 personnel. About 100 of these were engineers and scientists. The following table lists the Linde Engineering Laboratory personnel who were active in the concrete reservoir project and the relationship of the Laboratory to Linde New York Office Management.

New York Office	- President - S. B. Kirk
	Vice President - L. A. Bliss - M.E. - 28 years Linde Service
	Vice President - P. B. Pew - M.E. - 25 years Linde Service
Tonawanda Engineering Laboratory	- Manager - G. J. Boshkoff - M.E. - 25 years Linde Service
	Assistant Manager - M. A. Dubs - Ch.E. - 8 years Linde Service
	Division Engineer - P. M. Riede - M.E. - 13 years Linde Service
	Engineer - J. H. Beckman - M.E. - 2 years Linde Service
	Engineer - E. C. Kent - M.E. - 8 years Linde Service
	Engineer - C. F. Fails - M.E. - 1 year Linde Service
	plus
	Other Supervisors and Engineers with M.E., C.E., E.E., and Ch.E. degrees, technicians, chemists, and draftsmen participated as required.

Mr. Pete Riede's contacts with the Preload Corporation were mainly with:

Mr. J. J. Closner, Vice President of Marketing
Mr. Fornerod, Chief Engineer

EXHIBIT A-1

PHYSICAL PROPERTIES OF NOMINAL 6000 PSI TYPE I - 28 DAY CONCRETE

Age Tested Days	No. Thermal Cycles 70°F to -320°F	Compressive Strength - psi 70°F	Compressive Strength - psi -320°F	Modulus of Rupture - psi 70°F	Modulus of Rupture - psi -320°F
30	0	6560	14,500	536	833
60	0	7130	13,300	694	1020
60	10	6250	13,300	212	470
100	25	6530	11,300		

Maximum Allowable Compressive Stress specified for design = 1/2 6000 = 3000 psi

Maximum Allowable Flexural Stress specified for design = 400 psi

Compressive Modulus of Elasticity = 4×10^6 psi at 70°F and 4.5×10^6 psi at -320°F

Coefficient of Thermal Expansion = 4.7×10^{-6} per °F for temperature range 70°F to -320°F

Coefficient of Thermal Conductivity = 8 B.t.u./sq.ft./hr.,°F/in. for temperature range of 70°F to -320°F

Coefficient of sliding friction between concrete and concrete lubricated with graphite = 0.12. Value specified for design = 0.5.

Density of Concrete = 147 lb/cu.ft.

Permeability = Negligible under a 31 ft. head of liquid oxygen

EXHIBIT A-2

PHYSICAL PROPERTIES OF OTHER MATERIALS IN RESERVOIR

WIRE

	Ultimate Tensile Strength - psi		Impact Values ft.lb.	
	70°F	-320°F	70°F	-320°F
Preload Cold Drawn Carbon Steel	230,000	301,000	23	24
303 Stainless Steel (for comparison)	116,000	160,000	36	41

PRELOAD PRESTRESSING WIRE

	Horizontal 0.162" Diam. Reduced to 0.141" Diam.	Vertical 0.196" Dia.
Maximum Allowable Stress, psi	152,000	173,000
Initial Applied Stress	140,000	170,000
Losses	20,000	20,000
Design Stresses	100,000	140,000

Coefficient of Thermal Expansion - 10^{-6}/°F - for Room to -320°F Temp. Range

Preload Wire	= 5.0	Everdur	= 7.6
Low Carbon Steel	= 4.9	18-8	= 7.0

Conductivity Values - B.t.u./hr./sq.ft.,°F/in. - for Room to -320°F Temp. Range

Perlite Powder Insulation	= .24
Foamglas	= .38
Perlite Concrete	= .6

Ultimate Compressive Strength of Perlite Concrete = 250 psi

Ultimate Compressive Strength of Foamglas = 150 psi

Maximum Internal Pressure developed by powder insulation = 40 lb./sq.ft.

Heat of Vaporization of liquid oxygen = 92 B.t.u./lb.

Allowable soil loading = 5000 lb./sq.ft.

Densities - lb/cu.ft.

Perlite Powder Insulation	= 6.5
Foamglas	= 10
Liquid Oxygen	= 71

EXHIBIT A-3

ENGINEERING CASE LIBRARY

ECL-164B

CONCRETE LIQUID OXYGEN RESERVOIR (B)

Early in 1951, the Linde New York Office and Tonawanda Engineering Laboratory Management decided to design and build a prototype concrete liquid oxygen reservoir of 266,000 gallon capacity. Such a size was large enough to confirm the validity of a concrete design and also make known possible unexpected deficiencies which should be corrected before larger capacity reservoirs were constructed.

Prepared for the Engineering Case Program by Mr. H. C. Kornemann with support from the National Science Foundation.

CONCRETE LIQUID OXYGEN RESERVOIR (B)

266,000 GALLON PROTOTYPE

Linde contracted with Preload to design and build the liquid oxygen reservoir. The design was a cooperative effort in which Preload supplied their experience with prestressed concrete tanks and Linde their low temperature information. Preload quoted a fixed price to Linde. This was subsequently increased somewhat as the scope of the work increased.

Preload's arrangement with Linde during the development, design, and construction of the first LOX tank LR-30 evolved out of the research and development that Preload had done under contract with Linde which preceded the design and construction of the LR-30 tank. This contract provided for Preload to undertake certain design work and investigations and for Linde to provide certain tests and investigation of material properties to be acquired in order to implement the design. The agreement also provides that any developments or patents that evolve would be owned by Linde. The patent did issue with respect to the prestressed concrete tank, and in the 1960's Preload took license from Linde for this patent. For the LR-30 tank specifically following the development phase Preload undertook the work on a lump-sum design and construction contract.

In the engineering area, Mr. M. F. Fornerod was Chief Engineer of Preload at that time as he had been for a number of years. Mr. Fornerod left the company about 1953 however. Design engineers in connection with the project included Mr. Felix Dushnick, who continues with Preload at the present, and Mr. Herbert Weiner and Mr. Nicholas Rouzsky. Mr. Weiner is no longer connected with the Preload organization, although Mr. Rouzsky is with the licensee in Spain.

J. J. Closner was assistant general manager at the time, responsible for both engineering and construction in sales activities.

Appended drawing, Exhibit B-1, is a cross section of the reservoir and its connections. The reservoir consisted of an outer prestressed concrete vessel 46'-4" O.D. and 49'-4" in height, with a domed roof and flat floor. The inner prestressed concrete vessel was 38' I.D. and 35'-4" in height. It had a domed roof and thin stainless steel floor which rested on a concrete-Foamglas insulated foundation. The sides and top were insulated with Perlite powdered insulation. Piping and safety devices for operation were provided. A metal liner was not required or provided to seal the concrete walls of the inner vessel. However, a carbon steel bar ring was cast into the wall of the inner vessel near the top so that, if it was found to be necessary in the future, a stainless steel liner could be easily installed. The gas phase working pressure was 8" H_2O.

The inner vessel for liquid oxygen resembled an inverted concrete tumbler. The cylindrical wall rested on and was free to move or slide on its footing ring. This prevented destructive stresses from occurring between the wall and footing during cool-down or warm-up of the reservoir. The bottom of the inner vessel was sealed by a 20 gage stainless steel membrane which rested on insulation. The inner vessel was to be suitable for a maximum temperature gradient of 20°F at the bottom of its 8" thick wall and a 10°F gradient at the top of the wall. These conditions might exist during cool-down and warm-up. During normal operation the gradient would be about 10% of these values. Six thousand psi compressive strength concrete was selected

for the inner vessel because it had high compressive strength, the best resistance to temperature cycling, greatest durability, lowest shrinkage upon setting, negligible permeability and the advantage of the corresponding high tensile strength.

HORIZONTAL PRESTRESSING

The cylindrical wall was prestressed by tightly winding it with .162" wire, with tension induced by drawing the wire through a .141" dia. die. The resistance caused by the aperture of the die being smaller than the wire induces the stress in the wire by elongation and by raising the temperature of the wire. The die is fixed on the prestressing machine as you can see in some of the literature and photographs. The machine drives itself around the tank by engaging an endless chain driven by sprockets from an engine on the machine. The initial stress of the wire was 140,000 psi, but to allow for plastic flow and concrete shrinkage the value chosen for design was 100,000 psi. A ¾" thick pneumatic mortar coating was applied over the wire to protect it and maintain most of the wire prestressing in the event that a few wires broke. Exhibits B-2 and B-3 show the wire winding machine applying the prestressing wire to the concrete wall. Exhibit B-4 is a description of the machine and its operation.

BOTTOM OF THE WALL OF THE INNER VESSEL

The first foot of the wall was prestressed by means of 39 wires to apply a compressive prestress in the 8" thick concrete of 634 psi.

A 20°F temperature gradient across the wall would produce a tensile stress on the inside of the wall and a compressive stress on the outside of the wall when the vessel was being cooled down. The stresses would be reversed during warm-up. The stress due to the 20°F temperature gradient was calculated to be 212 psi.

$$\text{Concrete stress} = \tfrac{1}{2} \times E \times \Delta T \times a$$

E = Modulus of Elasticity
ΔT = Temperature Gradient
a = Coefficient of Thermal Exp.

$$= \tfrac{1}{2} \times 4.5 \times 10^{6} \times 20 \times 4.7 \times 10^{-6}$$

$$= 212 \text{ psi}$$

Prestressing eliminated the 212 psi tensile stress in the concrete.

The 30'-11" head of liquid oxygen would have developed a tensile stress of 550 psi in the concrete. This tensile stress was counteracted by prestressing.

Part of the compressive prestress was also used to counteract the friction forces of about 250 psi which might develop during temperature changes as the concrete wall slid on the concrete footing.

The number of wires and required prestressing were reduced as the height above the footing increased.

TOP OF THE WALL OF THE INNER VESSEL

The top foot of the wall was prestressed by means of 42 wires to apply a compressive prestress in the concrete wall of 682 psi. This was used to counteract the thrust of the concrete dome plus insulation and the 10°F temperature gradient during cool-down and warm-up.

VERTICAL PRESTRESSING

The inner vessel wall was vertically pre-

stressed by casting vertical bundles of 12 hard drawn carbon steel wires 0.196" diameter, located about four feet apart (see Exhibit B-5). The wire was threaded through a thin vertical carbon steel tube with loops formed in the wire at the base. A tube for pressure grouting extended from the steel tube, which was around the vertical prestressing wire, to the outside of the wall. Eight days after the wall was poured, the wires were stretched, keyed into position and grout was forced into the vertical carbon steel tubes. The tensile stress developed was 182,000 psi which permitted a design stress of 140,000 psi.

The prestress induced in the concrete was 132 psi to which were added 9 to 41 psi dead loads.

The maximum vertical stresses would occur during cool-down and warm-up. They would be caused by prestressing, temperature gradients, and friction forces on the footing.

STAINLESS STEEL FLOOR

This was the third major novel element of the concrete liquid oxygen reservoir. The others were discussed previously; namely, the use of concrete and carbon steel wire at -297°F.

The floor of the inner vessel was 20 gage (.0375") type 304 stainless steel. It was welded at the periphery to a 1" x 3/16" stainless steel angle which was welded to a one-foot-high skirt. This, in turn, was welded to a 1" x 2½" carbon steel ring which was cast into the inner concrete wall to complete the bottom seal. Carbon steel was chosen for the ring because its coefficient of expansion was about the same as concrete.

The stainless steel floor accomplished the following:

1. It simplified the design of the concrete wall of the inner vessel. The wall was free to slide on its footing. The inner vessel and footing were designed to be cooled through a temperature range of 410°F (90°F to -320°F). Its 38 ft. diameter would change 0.8 inches. This would be the maximum relative movement between the wall and footing and would depend upon their relative speed of cool-down. The friction coefficient was minimized by troweling in graphite on the top of the concrete footing before it hardened.

2. It provided a tight metal floor. This could not be assured by a concrete floor tied into the cylindrical wall. There would have been a very good possibility of the floor and/or the tied-in concrete joints cracking from excessive and uneven temperature stresses.

3. It provided positive welded metal joints to all pipe connections to the bottom of the inner vessel. During cool-down the Everdur piping would shrink about 1" between the point where it was welded to the stainless steel floor and metal sleeves imbedded in the wall of the outer vessel. Changes in the pipe length were compensated for by means of bends in the piping.

4. It provided a collecting pan so that liquid oxygen, which was initially added through the floor, would be uniformly distributed and evaporated over the floor area. The stainless steel floor would cool down first. Its diamter would be reduced by 1¼" and cause bending stresses to develop in the stainless steel skirt as the bottom of the concrete wall and its 1" x 2½" imbedded carbon steel ring would cool down much more slowly.

5. The uniform distribution and evaporation of liquid oxygen on the stainless steel floor facilitated the uniform and gradual cool-down of the concrete inner vessel, insulation and foundations. Stresses in the

concrete were thus minimized.

The stainless steel floor and the liquid oxygen were supported by a 7" slab of Perlite concrete which, in turn, rested on a 40" thick pad made of Foamglas blocks. These also supported a concrete footing ring which carried the weight of the concrete inner vessel. The Perlite concrete slab had some insulating value. It also protected the fragile Foamglas from thermal shock and mechanical damage from the stainless steel floor and piping. The Foamglas blocks were supported on the 4" thick concrete floor of the casing. The concrete floor was free to move vertically with respect to the casing wall. Finally, a one foot layer of compacted sand was provided between the casing floor and ground.

The heat leak through the insulated foundation was calculated to be 3.4 B.t.u./hr./sq. ft., 4100 B.t.u./hr.–about 24% of the heat leak for the entire tank. The heat loss into the ground might eventually freeze the ground and damage the foundations, insulation and the reservoir. In order to avoid freezing the ground, a grid of electric heating cables was installed on the ground below the compacted sand. Five cables with a total heating capacity of 4000 watts (13,600 B.t.u./hr.) were installed with a thermoswitch to maintain the ground temperature at 35^{o}F. This arrangement was considerably less expensive than providing a space under the insulation and outer vessel for circulating atmospheric air under the casing.

OTHER ITEMS OF INTEREST IN DESIGN

The outer vessel was also made of prestressed concrete and provided a space of 36" along the sides and 46" at the top for Perlite insulation powder. The prestressed section of the outer vessel was prestressed by means of 4500 lbs. of hard drawn carbon steel wire (1.2% of the weight of the concrete) whereas the wall of the inner vessel was prestressed by means of 7200 lbs. of hard drawn carbon steel wire (1.9% of the weight of concrete in the wall).

In order to provide additional safety, the amount of steel used for prestressing the outer vessel was increased somewhat above the amount normally provided for atmospheric tanks. Also, all the manholes located near the bottom were sealed. These features would allow the outer vessel to act as a safety device to hold liquid oxygen in the event a major leak developed in the inner vessel.

Pipe connections were provided to add and remove liquid, for venting of gas and liquid, and to measure the contents of the reservoir. Thermocouples were installed at strategic points–at foundations, under the insulation, at the dome, and on the inside and outside of the wall of the inner vessel, to measure temperatures during cool-down operation and warm-up.

The heat leak into the reservoir was calculated to be equivalent to the daily evaporation of 0.2% of the reservoir's capacity. This was so low that if the barometric pressure increased rapidly the vapor pressure of the liquid oxygen would be less than atmospheric pressure, evaporation would stop, and atmospheric air containing moisture would enter the reservoir through vents. Atmospheric air entering the reservoir would be objectionable and dangerous as the moisture in the air would freeze in the vent piping and plug it. Also, the purity of the oxygen in the reservoir would be reduced by the nitrogen in the air. In order to prevent this, vents were provided which would relieve oxygen to the atmosphere but would close and prevent atmospheric air from entering the reservoir. In order to avoid a vacuum, means were provided to add oxygen gas to the inner vessel when required to assure a slight positive

pressure there.

As the reservoir was to be installed on sloping ground—over an abandoned coal mine—a drainage ditch was provided around the outer casing and connected to a 10,000 cu. ft. collecting basin. Such a basin was installed as a safety measure to collect liquid oxygen in the event both the inner and outer vessels failed.

CONSTRUCTION

The reservoir was installed in a Linde liquid oxygen producing plant near Pittsburgh, Pennsylvania. The Preload Corporation built the concrete portions, including the concrete forms, and prestressed the concrete. Linde, through its Construction and Design Department, provided and installed the stainless steel floor, internal piping, and the external piping to connect the reservoir to the Linde Plant piping system.

As the reservoir was to be used in liquid oxygen service, it was necessary that all the aggregate used for the concrete be free of carbonaceous materials. Neither could the usual "form" oil be applied to the inside of the concrete forms to facilitate their removal. A mixture of water-glass and graphite (which was satisfactory for oxygen service) was used to coat the forms. Most of the graphite was removed by brushing prior to adding liquid oxygen to the reservoir.

The entire 91 cubic yards of 6000 psi concrete, required for the wall of the inner vessel, was poured continuously during a single day to eliminate possible cracks and leakage. This was considered quite a feat because the high strength concrete, which had only a small amount of water, flowed with difficulty.

Construction started during June 1951 and was completed in March 1952.

OPERATION

The reservoir was placed in operation and filled with liquid oxygen by the Linde Production Department with the aid and consultation of the Linde Engineering Laboratory, who specified and prepared the operating instructions. The inside of the reservoir and oxygen piping were thoroughly cleaned for oxygen service and dried before oxygen was added.

Liquid oxygen was added to the stainless steel floor at a rate such that the maximum temperature gradients through the inner vessel wall would be no more than 20°F at the bottom and 10°F at the top of the wall. During the first seven days of cool-down, liquid oxygen was added slowly and the level was kept below the top of the 12" stainless steel skirt of the floor. See Exhibit B-6 for temperatures during cool-down.

The maximum thermal gradient across the wall six inches above the footing was 17°F. It occurred 12 hours after liquid oxygen was first added to the floor. Twenty-two hours after filling started, the maximum temperature gradient of 14°F was measured at the 5-foot level. At the 28-foot level, the maximum temperature gradient of 10°F occurred eight days after the start of filling when the liquid level was about two feet above the footing.

The maximum vertical thermal gradient of 31°F per foot occurred between the 6-inch and 5-foot levels on the seventh day of filling. Between the 5- and 28-foot levels, the maximum gradient of 6°F per foot did not occur until 21 days after start of filling.

Filling started in March 1952 and the reservoir was finally filled in May, 62 days later. Of the 37,675,000 cu.ft. (N.T.P.) of liquid oxygen added to the reservoir, 3,870,000 cu. ft. were required to cool down the concrete, insulation, etc., and 3,417,000 cu. ft. were required for normal heat leak.

Later in 1952 the reservoir was emptied and warmed up over a 50 day period. Inspection showed the inside concrete wall to be in satisfactory condition. Several minor leaks were repaired in the welds of the stainless steel floor and the lower 7 feet of the concrete wall were painted with water-glass.

The prototype reservoir was then turned over to the Linde Production Department for normal operation in November 1952. Operation was satisfactory.

660,000 GALLON RESERVOIR

Early in 1953, Linde authorized the Preload Corporation to build a 660,000 Gallon Reservoir for liquid oxygen at its East Chicago, Indiana, production plant. This reservoir was 67' O.D. and 53' in height. The inner vessel was 56'-3" I.D. and 36' in height. The design was essentially the same as for the prototype reservoir. However, the thickness of the stainless steel floor of the inner vessel was increased to 16 gage and an "improved" joint was provided between the concrete wall and stainless steel skirt.

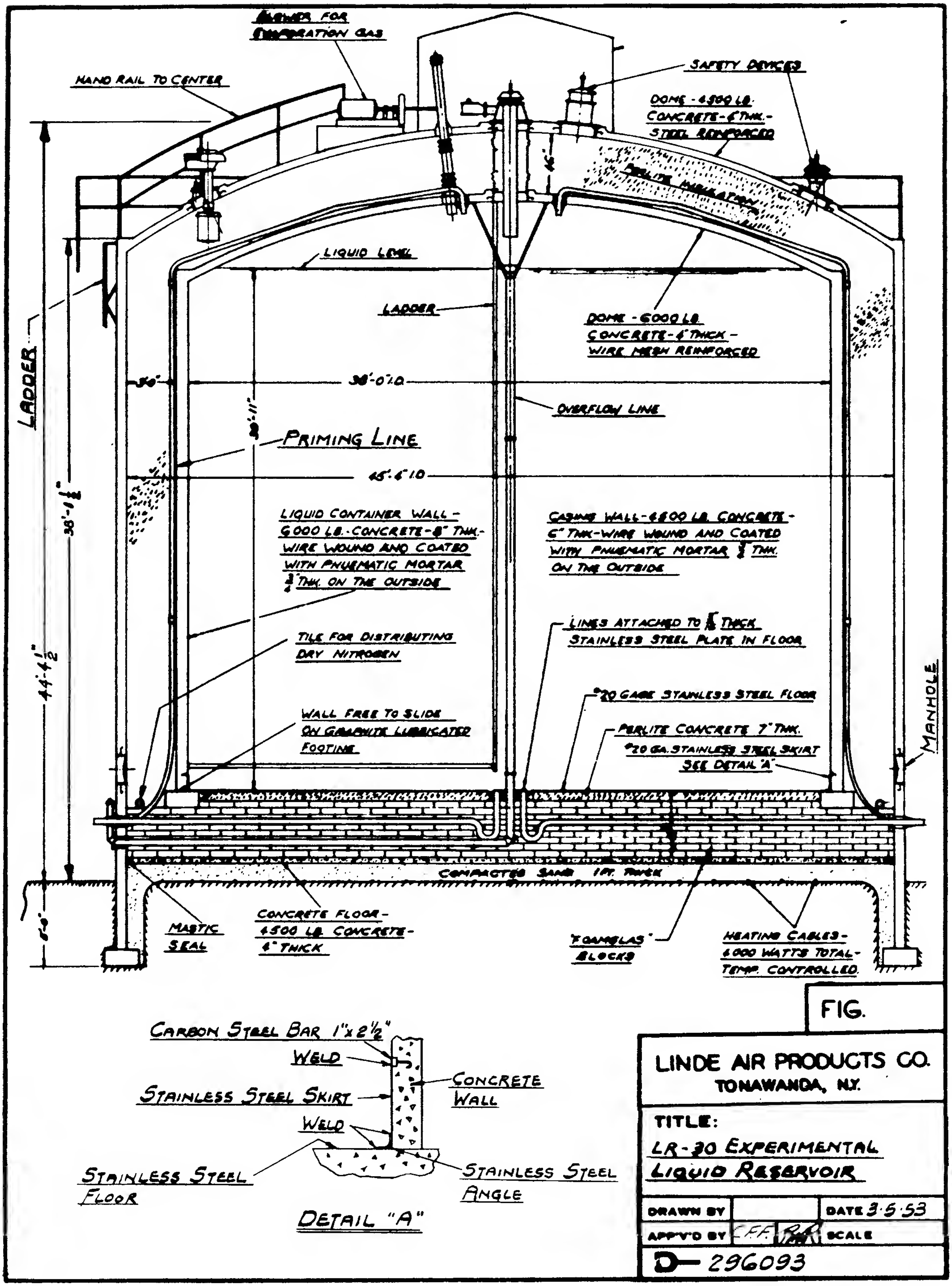
The reservoir was placed in service in 1954. In 1958 the joint between the concrete wall and stainless steel skirt, which had developed an objectionable leak, was permanently repaired by welding to the skirt ring a stainless steel curb, 6" wide by 18" high, and filling it with concrete. The reservoir continues in satisfactory condition as of the present date.

U.S. Patent No. 2,777,295, covering the design of the concrete reservoir for liquefied gases, was granted to Messrs. L. A. Bliss, P. M. Riede, and J. H. Beckman. The Preload Corporation was licensed by the Linde Company to use this patent and has built additional prestressed concrete reservoirs for liquefied gases.

In recalling the project Mr. J. J. Closner, now Vice President of Preload, said, "Very little came out of the work we did with Linde until the early 1960's. We found no markets for the prestressed concrete LOX tanks since their initial cost was somewhat more than stainless steel tanks at the time, and the size of the tanks were small. However, in the early 1960's the American Gas Association became interested in the possibilities of using prestressed concrete for the storage of liquefied natural gas for peak-shaving plants. Preload undertook a further development contract with the American Gas Association and the Institute of Gas Technology to accomplish this investigation and to add and to extend the information which was made available from Linde at that time. This resulted in the use of prestressed concrete tanks for the storage of liquefied natural gas. Of most interest to us is that these tanks are in the range of 600,000 to 800,000 barrels. Our studies are now taking us up to LNG tanks beyond 1,000,000 barrels of capacity."

H. C. Kornemann

Dated: August 21, 1970



3-5-53 REPRODUCED FROM B-286499

EXHIBIT B-1

EXHIBIT B-2

Horizontally prestressing the casing with 0.162 in. dia. high carbon steel wire, January 28, 1952. The lower carriage is pulled from left to right by a sprocket which engages the chain about the tank.

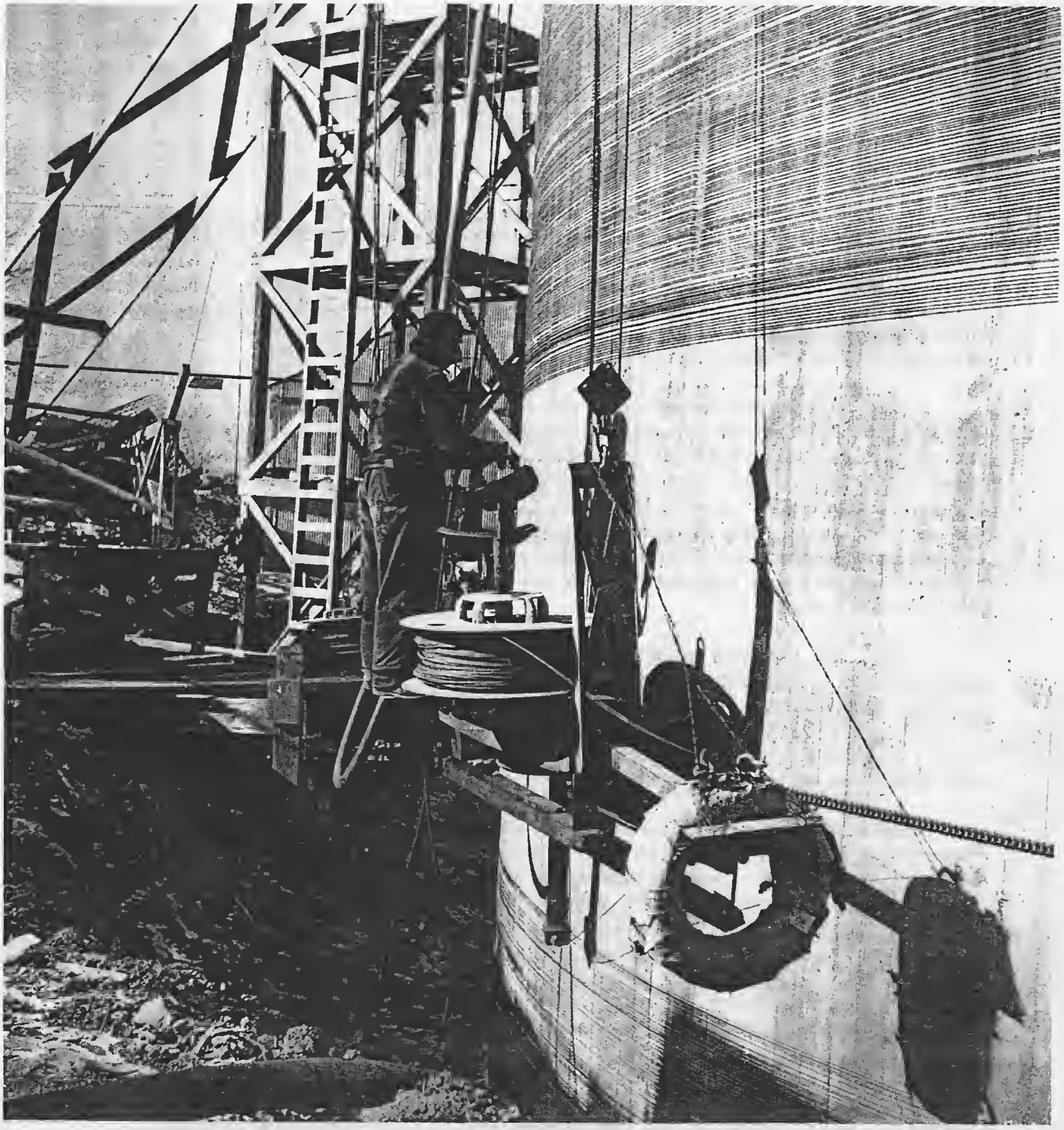


EXHIBIT B-3

Wrapping the lower portion of the casing by drawing the wire through a 0.142 in. dia. die. The wire winding machine is powered by air.

DESCRIPTION OF WIRE WINDING MACHINE

The self-propelled wire winding machine, see Exhibits B-2 & B-3, was suspended by cables from a traveling carriage on the top of the wall. The carriage was pivoted from a center post which was bolted to the dome and held in proper alignment by cables. The operator spaced the wires by raising or lowering the wire winding machine with an air motor located on the upper carriage.

The wire winding machine, see Exhibit B-3, consisted of a vertical pipe, the end of which contained the 0.142 inch diameter wire reducing die. The vertical pipe was fastened to a frame and an air motor driven sprocket gear which meshed with a heavy roller chain that encircled the wall. A 400 lb. roll of 0.162 inch diameter wire, the end of which had been previously reduced to 0.142 inch diameter, was placed on the machine, the elongated end of the wire was threaded through the die and fastened to an expansion shield bolt anchored in the concrete wall.

The 140,000 psi initial stress in the wire was obtained by simply pulling the wire through the die as the air motor driven wire winding machine wrapped the wire around the wall.

Exhibit B-3 shows the wire winding machine, with the die below the frame, winding the wire upward near the end of winding operation.

Wire winding was started near the top of the wall and progressed downward. The die was above the machine because the chain drive was below the machine. This arrangement made it less likely to nick or damage the wire. In order to wrap the bottom of the wall, it was necessary to reverse the position of the die, see Exhibit B-3, and wind upwards.

The ends of the wire from the various rolls were joined together (after passing through the die) by means of carbon steel collets. Clamps were used to bind several turns of wire together and were placed on the windings whenever the machine stopped and whenever a new roll was added. The clamps were left in place so that if a wire should break the number of turns which would loosen and have to be replaced would be minimized.

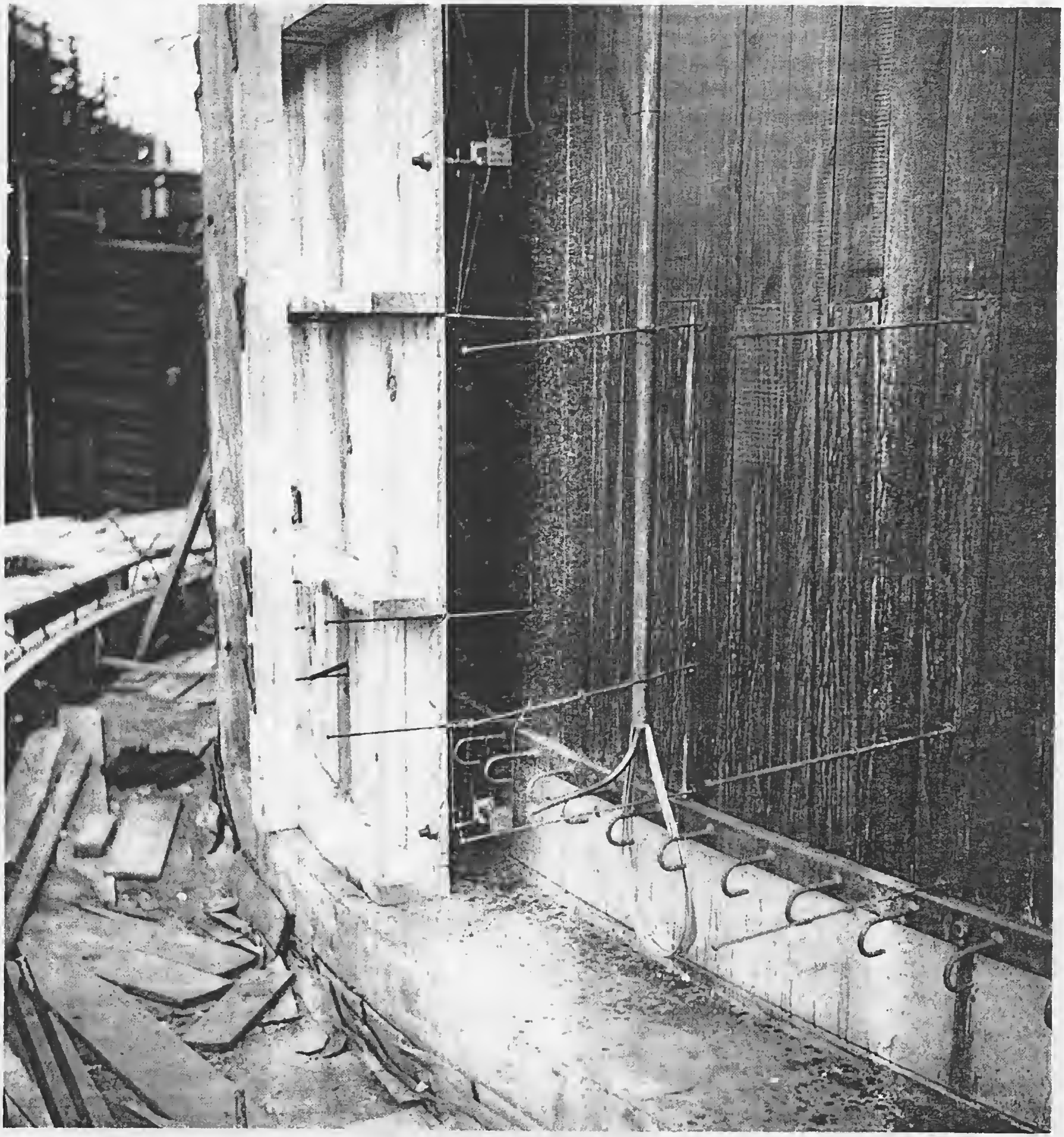


EXHIBIT B-5

Vertical bundle of 0.196 in. dia. galvanized prestressing wires. Note the location of the grouting tube. The bar ring and skirt is in position against the inner form. Note the holes drilled through the bar ring.

INITIAL TEST OF LR-30 RESERVOIR

SOUTHEAST WALL TEMPERATURE GRADIENTS

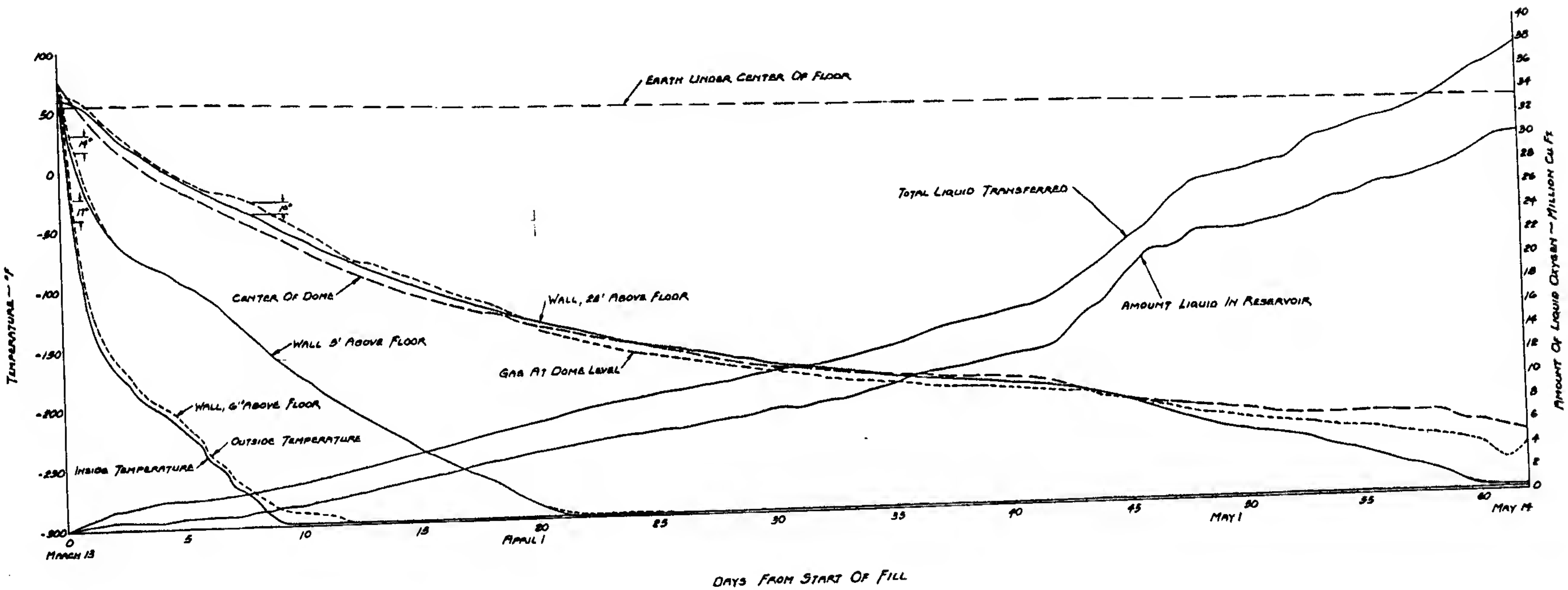


EXHIBIT B-6

INSTRUCTOR'S NOTE

Concrete Liquid Oxygen Reservoir

This case study gives the instructor in opportunity to introduce the student to the design of equipment involving thermal stresses, in particular, the storage of cryogenic liquids. The first part of the case introduces the student to the background of the design and places before him the fundamental information on which the design is to be based. The second part of the case gives the student the final design generated by the principles in the case.

Based upon reading the first part of the case class discussion can be centered around:

1. The preferred storage tank configuration
2. The merits of concrete for low temperature application.
3. Where and how prestressing could be applied.
4. The significance of the carbon steel reinforcing wire having the same coefficient of thermal expansion as concrete. Is this important in non-cryogenic use?
5. Criteria for establishing the prestressing required and working stresses in the reservoir.

The first part of the case can also be used as a basis for design projects or design analysis problems. By giving the students some of the information available in part B of the case such as over-all dimensions, the student can be asked to determine the following:

1. Maximum stress gradient in reservoir walls.
2. Steady state stress gradient in reservoir walls.
3. Thermal stress in reservoir walls.
4. Prestressing in reservoir walls.
5. Tank filling procedure.

Part B of the case can be assigned for reading so that the students can compare their analysis and design with that of the principles in the case.

Class discussion on Part B of the case can be centered on:

1. Method of applying prestressing and control of prestressing.
2. Why prestressing is different at different parts of the wall.
3. Why vertical prestressing
4. Problem of joining stainless steel to carbon steel.
5. The merits and significance of the design details discussed in the case.